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THE EFFECT OF PROPOSED CRUSH TESTS ON TRANSPORT CONTAINERS

by

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RESEARCH REPORT

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THE EFFECT OF PROPOSED CRUSH TESTS ON TRANSPORT CONTAINERS

ABSTRACT

Crush tests were performed on two AECL F112 packaging specimens, two simulated AECL-CRNL 4H packaging specimens, and on empty steel drums. The 9m drop test was carried out on two simulated AECL-CRNL 4H packaging specimens for comparison with the effects of the crush test. The tests were filmed using high speed photography and 35mm still photographs.

RÉSUMÉ

Le présent rapport fait état des résultats des épreuves d'écrasement auxquelles on a soumis deux conteneurs F-112 de L'EACL, deux échantillons d'emballages 4-H simulés des laboratoires nucléaires de L'EACL à Chalk River (L'EACL-LNCR) et des barils d'acier vides. Il rend compte également des résultats de l'épreuve de chute libre de 9 m à laquelle ont été soumis deux échantillons d'emballages 4-H simulés de L'EACL-LNCR et les compare aux effets de l'épreuve d'écrasement. Les essais ont été filmés avec une pellicule rapide et photographiés avec un film de 35 mm.

DISCLAIMER

The opinions expressed in this report are those of the authors and do not necessarily reflect those of the Atomic Energy Control Board.

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1.0 Introduction

This report presents the results of tests carried out on type "B" packaging designed for use in the transport of radioactive materials, (namely the AECL-CP F112 transport packaging and dummy packaging designed to simulate the AECL-CRNL 4H packaging), and on empty steel drums. The purpose was to assess the effects of the dynamic crush test recently proposed by the International Atomic Energy Agency, (IAEA), Vienna.

The work was carried out for the Atomic Energy Control Board (AECB) under the terms of a Department of Supply and Services, (DSS), contract, ref. DSS File No. 02SQ .87055-3-4075.

The discussion which follows describes the technical aspects of the work performed.

2.0 Technical Discussion

2.1 General

Packaging designed for the transport of radioactive material is designated as type "A", or type "B". In order for the type "B" designation to be applicable, the packaging must be able to withstand certain conditions referred to as accident conditions. The IAEA have established tests which are intended to be representative of accident conditions; if, following these tests, the packaging can meet certain acceptance criteria, it may be considered as meeting the requirements for type "B" packaging under accident conditions.

One such group of tests, referred to as mechanical tests, consists of three drop tests. Drop I is referred to as the pin-drop, drop II the dynamic crush test, and drop III, the 9 meter drop test. The packaging must be exposed to drop I, and drops II or III, depending on the package mass, density, and contents; drop II, the the dynamic crush test being applicable only to packages whose mass does not exceed 500 kg, whose density does not exceed 1000 kg/cubic meter and, whose radioactive contents do not exceed 1000 A2 not as special form radioactive material. Drop III, the 9m drop is applicable to all other type "B" packaging.

Drop I, the pin-drop test, consists of dropping the packaging a distance of 1m onto a solid mild-steel bar, 150mm diameter by 200mm long (or longer if a longer bar would result in greater damage), mounted on a target as described below. The attitude of the packaging on impact is to be such as to cause maximum damage.

Drop II, the dynamic crush-test, consists of dropping in a horizontal attitude, onto the packaging, a flat mild-steel plate 1m x 1m having a mass of 500 kg, from a height of 9m measured from the underside of the plate to the uppermost point on the packaging; the packaging being positioned on a target in such way as to cause maximum damage to the packaging; the target being a flat horizontal surface whose character is such that any increase in its resistance to displacement or deformation on impact will not significantly increase the damage to the packaging. As mentioned previously this test is applicable only to packages whose mass and density are not greater than 500 kg and 1000 kg/cubic meter respectively.

Drop III, the 9m drop test, consists of dropping the packaging a distance of 9m, measured from the underside of the packaging, onto a target as described above.

Since the orientation of the packaging during the test is to be such as to result in maximum damage, for purposes of the tests carried out in this report it was assumed that if two specimens were subjected to the same tests under ideally identical conditions the resulting damage would be identical or nearly so. Therefore to obtain as much information as possible, the tests were performed with one specimen in a horizontal attitude and the other in a vertical attitude.

2.2 Objectives

Currently all type "B" packaging has to be subjected to the 9m drop test. Recently the IAEA has proposed that a dynamic crush test also be included in the series of tests used for testing type "B" packaging. Therefore there were two objectives of the work performed in this report. The first was to determine the behaviour of AECL-CP F112 packaging and empty steel drums of different sizes under dynamic crush test conditions and the second was to compare the effects of the dynamic test with the effects of the 9m drop test on simulated AECL-CRNL 4H packaging. Simulated specimens were used because the cost of an actual packaging specimen was prohibitive considering the objectives of the project. The pin-drop test was considered not relevant to the objectives of the project.

In order to assess the effects of the drop tests, the folowing tests, measurements, and documentation were carried out.

a) Leakage tests were performed on the F112 internal containers before and after the drop tests.

b) Strains and accelerations in the internals of the F112 and simulated AECL-CRNL 4H packaging specimens were measured during the tests. (This was not successful. On the first drop, the accelerometer failed to trigger the oscilloscope and no strain or acceleration data could be obtained. During drop test 4 the accelerometer was damaged beyond repair and measurement of accelerations had to be abandoned also, no data was recorded. Because of the lack of data that was recorded, that which was recorded is not particularily usefull however, it is presented in Appendix 1 of this report.

c) A slow motion film was made.
d) 35mm photographs were taken.
e) Written documentation was made of visual damage.

2.3 Work Performed

In order to achieve the objectives and record the observations and data mentioned above, the following was performed.

a) The AECB provided two AECL-CP F112 packaging specimens. The specimens are shown in Figure 3. Details are given in AECL Commercial Products drawings:

A 01986 issue A
A 01987 issue D
A 06016 issue B
A 06018 issue A

b) Four specimens were fabricated as shown in Figure 1. These simulate the AECL-CRNL 4H packaging.

c) Two new 208 litre empty steel drums, (20 Ga.) and two reconditioned 114 litre empty steel drums, were purchased (20 Ga.)

(Empty steel drums, 208 litres, 140 litres, 80 litres, and 40 litres were to be subjected dynamic-crush test only. However, because of lack of availabilty of small drums, tests could be carried out using only 208 litre and 114 litre drums.)

d) The Monserco drop test facilty shown in Figure 2 was set up to allow dropping of a 1m x 1m mild -steel plate having a mass of 500kg.

e) The air-bubble-vacuum-and-glycol leakage test described in ANSI N14.5-1977, was carried out on the internals of the F112 specimens before and after the drop tests to determine if any damage, that could not be seen by the naked eye, had occured as a result of impact. Leakage testing of the simulated AECL-CRNL 4H packaging specimens and empty drums was considered inappropriate since these are not designed to prevent small leakages.

f) A single accelerometer and strain gauge were installed on the internals of the F112 and simulated AECL-CRNL 4H packaging specimens. Electronic equipment, a Tektronix 7613 oscilloscope, Tektronix 7D20 programmable digitizer, and HP 85B computer, were used to collect and transfer data directly to Monserco's VAX 11/750 computer. Acceleration-time and strain-time plots are presented in Appendix 1 of this report.

j) High speed photography, sub-contracted to Photographic Analysis Limited, Markham, Ontario, was used to record the impact. The set-up is shown in Figure 2. For all drop tests except the dynamic crush test on specimen number 2, the camera speed was 1000 frames per second; for the test on specimen number 2, 300 frames per second had to be used because of loss of light late in the day.

k) The drop test described in reference 1 paragraph 732(b) was carried out on:

i) Two, AECL-CP F112 packaging specimens, serial numbers 23 and 39.
ii) Two, simulated AECL-CRNL 4H packaging specimens.
iii) Two, 208 litre empty steel drums.
iv) One, 114 litre empty steel drum.

l) The drop test described in reference 1 paragraph 732(c) was carried out on two simulated AECL-CRNL 4H packaging specimens.

The tests were performed outdoors. The ambient temperature during the time that testing was carried out ranged between 15 and 20C.

Prior to carrying out the tests the specimens were inspected for defects, none were observed except for small dents in the outer drums that would result from normal handling.

The tests conducted are shown in Table 1.

3. Results

3.1 F112 Packaging

3.1.1 Specimen Number 1

Specimen number 1 was subjected to the dynamic crush test in a vertical attitude. The effects can be seen in Figure 3 which shows specimen number 1 after impact along side specimen number 2, (an identical specimen), prior to testing.

From viewing the high speed film of the impact it appears that the impact was more severe than on the simulated AECL-CRNL 4H packaging specimen, the 4H specimen having a softer imapct absorbing layer. The 500 kg plate rebounded about 600mm compared with about 325mm for the test on the simulated AECL-CRNL 4H specimen, (scale markings 150mm apart on the drop tower and clearly visible in the film enabled distances to be estimated). The simulated 4H specimen "jumped" about 200mm off the surface of the target.

The upper section of the outer container was pushed down inside the formed stiffened section. The specimen was deformed vertically about 110mm making the average decceleration of the plate,

$$a = 9000/110 = 82g's$$

and the average force during impact,

$$f = 82 \times 500 = 41000 \text{ kg}$$

The lid remained in place during the impact and there was no apparent loss of containment.

Prior to carrying out the dynamic-crush test, the closure bolts on the inner container lid were torqued to 3.4 Nm, (compressing the rubber gasket) and the container leak tested using the air-bubble-vacuum-and-glycol leakage test described in ANSI N14.5 -1977; the test pressure was 720mm of mercury below atmospheric. Bubbles were observed coming from around the bolt heads which is to be expected since there is no gasket under the bolt heads and air trapped in the bolt-hole clearance between the bolt and closure head would be free to escape. No other bubbles were observed and it was concluded that the container was leak tight within the sensitivity limits of the test method. The leakage test was repeated following the crushtest; no change in leak tightness was observed.

The torque required to loosen the internal container closure lid bolts was measured following the second leakage test to determine if there had been any change in preload of the bolts. The torque varied between .6 and 1.7 N.m compared with the 3.4 N.m applied prior to the crush test. The bolts were then retorqued to 3.4 N.m and the loosening torque measured again. The loosening torque was approximately 2.3 N.m. Since the bolts had been torqued up and left for about 5 days before loosening it was concluded that the reduction in torque was most likely due to "gasket set" rather than impact.

3.1.2 Specimen Number 2

Specimen number 2 was subjected to the dynamic crush-test in a horizontal attitude. The effects of the test can be seen in Figure 4.

The lid of the outer container, shown removed in Figure 4 remained in place during the test. As can be seen, the container was flattened on both sides, the measured deformation was approximately 55mm. The average acceleration during impact would be

$$a = 9000/55 = 164g's$$

and the average force

$$f = 164 \times 500 = 82000kg$$

The internal container was held in place by wooden spacers. As can be seen in Figure 4 the circular cavity was deformed into an oval. Considerable difficulty was experienced in removing the inner container, the wooden spacers had to be broken and split to release the inner container, however there was no apparent damage to the container.

The leakage test carried out on the internal container prior to crush testing showed no leakage at the gasket. Bubbles were observed coming from two holes, used to mount the accelerometer, that were drilled through the outer steel shell and into the lead but not penetrating the inner shell. Following the test the bubble activity from these holes was much greater than before the test. The container was opened and examined internally. There, was no visible damage and no reason could be found for the change in bubble activity.

The bolt torques were checked in the same manner as described above and the results were such that the same conclusions could be made.

Viewing the high speed film, showed that the 500 kg plate struck the specimen squarely.

3.2 Simulated AECL CRNL 4H Packaging

3.2.1 Specimen Number 3

Specimen number 3, a simulated AECL CRNL 4H packaging specimen, was subjected to the dynamic crush-test in a vertical attitude. Figure 5 shows on the left an undamaged specimen, in the centre, specimen number 3, and on the right, specimen number 9, a simulated AECL CRNL 4H packaging specimen which had previously been subjected to a 9m drop test. A comparison of the effects of the dynamic crush test can easily be seen.

The high speed film showed that the specimen was struck squarely, the 500 kg plate rebounded about 250mm, fell back down onto the specimen and glanced off coming to rest against the side of the specimen. The specimen remained in place and did not "jump" up off the target.

Examination of the deformation of the outer container and inspection of the internals revealed that the upper impact absorbing section had been crushed down and the plywood sheet "punched out" by the 324mm pipe allowing the lid to come in contact with the pipe; the pipe can be seen in Figure 6. Beneath the vermiculite granules and between the 324mm pipe and the outer container, is a "punched out" annular ring of plywood pushed down so as to be in contact with the 38mm schedule 40 pipe stiffening ring that is bolted to the outer container. Beneath the vermiculite granules in side the 324mm pipe is a "punched out" plywood disc. This disc was pushed down onto the top of the accelerometer damaging the connector beyond repair. The 500 kg plate can be seen resting against the specimen.

The 324mm pipe was pushed down into the bottom impact absorbing section about 38mm.

The lid came off during the test apparently due to distortion of the drum at the closure.

There appears to be no buckling of the outer container below the lower formed stiffener, all of the damage to the container occuring in the upper sections.

3.2.2 Specimen Number 4

Specimen number 4, a simulated AECL CRNL 4H packaging specimen, was subjected to the dynamic crush-test in a horizontal attitude. The effects of the test are shown in Figure 7 along side specimen number 10, an identical specimen, which had already undergone the 9m drop test.

During the impact, the lid came off the outer container, (a 208 litre drum). The 38mm schedule 40 pipe reinforcement ring was deformed into an oval configuration.

The deformation measured was 160mm making the average decceleration and force:

$$a = 9000/160 = 56 \text{ g's}$$

$$F = 56 \times 500 = 28000 \text{ kg}$$

The high speed film shows the plate striking the packaging, bouncing back up about 250mm, then falling back down coming to rest on the specimen indicating a good straight-on hit.

3.3 208 Litre Drums

3.3.1 Specimen Number 5

Specimen number 5, a 208 litre litre empty, closed, 20 ga. steel drum, was subjected to the dynamic crush test in a vertical attitude. The drum was crushed, buckling unevenly, as shown in Figure 8. The average defomation was approximately 540mm making the average decceleration 10000/540 = 18g and the average force during impact 18 x 500 = 9000 kg.

The lid became detached during rebound of the 500kg plate. This is believed to be due to the entrapped air being compressed to approximately 275 kPa, (calculated by taking the ratio of the original height of the drum to the crushed height, i.e. 864/(864-540) = 2.7, times atmospheric pressure, 101.325 kPa). Outward bulging was clearly visible on inspection of the lid following the test.

Possible causes of the uneven buckling of the drum is the plate not striking the drum exactly on centre, not striking the drum exactly flat, and the drum not being a perfectly ideal specimen.

The 500kg plate rebounded about 500mm during the impact, (estimated from the tower markings in the high speed film), and landed upside down beside the drum. This is also believed to be due to compression of the air in the drum. A compression of 275 kPa would result in a pressure differential of 174 kPa and a force on the drum head of 44220 N, (4500 kg).

3.3.2 Specimen Number 6

Specimen number 6, a 208 litre empty drum, was subjected to the dynamic crush-test in a horizontal attitude. The drum was crushed flat as can be seen in Figure 9. Since the drum was totally flattened it can be assumed that "bottoming-out" occurred and the drum was not able to absorb all of the kinetic energy of the 500 kg plate.

3.4 114 Litre Drums

3.4.1 Specimen Number 7

Specimen number 7, an empty 114 litre drum, was subjected to the dynamic crush-test in a vertical attitude. The results were similar to the test on the 208 litre drum. One major difference was that the lid remained in place.

The drum was crushed a distance of 325mm resulting in an average decceleration and force during impact of:

$$a = 9000/325 = 28 \text{ g's}$$

$$F = 28 \times 500 = 14000 \text{ kg}$$

From the slow motion film of the impact, a distinct "spring back" of the drum of about 50mm can be seen. This is believed to be due to the retention of the lid and the force exerted by the compressed air. Bulging of the lid outward can be clearly seen in the photographs. Following the impact, air could be heard escaping from the drum.

The results of the test are shown in Figure 10.

3.4.2 Specimen Number 8

Specimen number 8, an empty 114 litre drum, was to be subjected to the dynamic crush-test in a horizontal attitude. Based on the results of the same test on a 208 litre drum, the drum was totally flattened, it was concluded that the same would occur with the 114 litre drum. Therefore, the test was not carried out.

3.5 Simulated AECL CRNL 4H Packaging Specimens (Group Two)

3.5.1 Specimen Number 9

Specimen number 9, a simulated AECL CRNL 4H packaging, was subjected to a 9m drop test in a vertical attitude. The specimen is shown, following the test, in Figure 5 along with specimen number 3, which has undergone a vertical crush test, and an identical undamaged specimen.

Some buckling can be seen at the bottom of the specimen and at the lower formed stiffener. The specimen rebounded about 200 mm and the high speed film shows that the buckling at the bottom occurred during the impact following the rebound. The film shows the specimen landing unevenly follcwing the rebound; this is believed to be the reason for the buckling on the second impact.

The outer container shortend by approximately 42mm and internals (the 324mm pipe filled with concrete) compressed the lower impact absorbing layer approximately 25mm.

The lid on the outer container remained in place during the impact.

3.5.2 Specimen Number 10

Specimen number 10, a simulated AECL CRNL 4H packaging, was subjected to a 9m drop in a horizontal attitude. There was some flattening of the outer container as shown in Figure 11. The drum-head remained in place. The deformation measured was 22mm. The internals were displaced radially about 25mm, compressing the urethane foam.

There was little or no rebound of the specimen.

4. Conclusions

4.1 Simulated AECL CRNL 4H Packaging Specimens

One of the objectives of the work performed in this report was to compare the effects, on simulated AECL CRNL 4H packaging specimens, of the 9m drop test with the effects of the dynamic crush test.

The results indicate conclusively that for the particular specimens tested, the dynamic crush test is more severe that the 9m drop test and that the simulated AECL CRNL 4H packaging after being subjected to the dynamic crush test would most likely not successfully withstand the fire test that would follow in the normal sequence of events in a complete test program. This conclusion is based on the acceptance criteria that the outer container must not rupture and the lid must remain in place such that there is no apparent change in leak tightness as a result of the mechanical test.

Comparing the energy that has to be dissipated in the two test methods, for the 9m drop the impact energy of the simulated AECL CRNL 4H packaging was 180 x 9 = 1620 kg-m and for the dynamic crush test, 500 x 9 = 4500 kg-m, 2.8 times that of the 9m drop.

In the case of the simulated AECL CRNL 4H packaging specimens, the lids came off as a result of deformation of the container, compression of the air trapped inside, and elasticity of the impact absorbing material. An improvement in the method of retaining the lid might result in the packaging being able to successfully withstand the dynamic crush test.

4.2 F112 Packaging

Another objective of the work carried out in this report was to determine the effects of the dynamic crush test on the F112 packaging. As mentioned above the results of tests carried out on the simulated AECL CRNL 4H packaging specimens indicate that the dynamic crush test is more severe than the 9m drop. This is most likely also the case for the F112's however, no definitive comparisons can be made since 9m drop tests were not performed on these.

Not withstanding the greater severity of the dynamic crush test, the results indicate that it is most likely that the F112's would survive the dynamic crush test such that the fire test, that would follow in the normal sequence of events in a complete test program, would not result in any more damage than that which would have occured had the packaging been subjected to the 9m drop test instead of the dynamic crush test.

4.3 Empty Drums

The third objective of the work carried out in this report was to determine the effects of the dynamic crush test on empty drums. The results indicate that when impacted in a vertical attitude the drums empty drums are able to absorb, without "bottoming out", all of the kinetic energy of the falling 500kg plate.

When subjected to the dynamic crush test in a horizontal attitude, empty drums are not able to absorb the kinetic energy without "bottoming out" mainly due to the inability of the lid to remain in place.

5. References

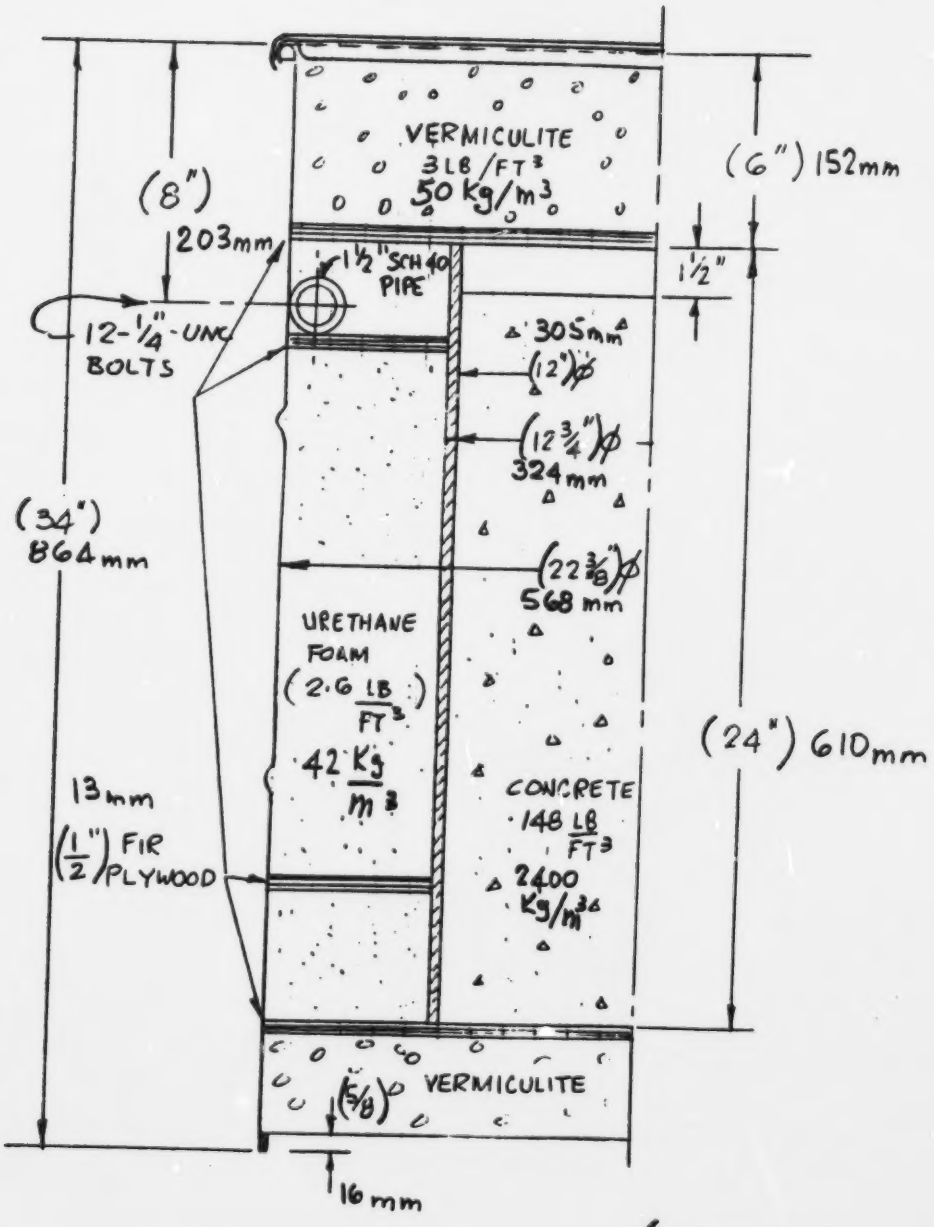
1. Regulations For The Safe Transport Of Radioactive Materials, IAEA Safety Standards, Safety Series No. 6, 3rd draft, October, 1982, International Atomic Energy Agency, Vienna.

Drop No.	Film No.	Spec. No.	Description	Drop Type	Specimen Orientation
1	-	5	208 litre drum	Dynamic Crush	Vertical
2	1	10	Simulated AECL 4H	9 meter drop	Horizontal
3	2	9	Simulated AECL 4H	9 meter drop	Vertical
4	3	3	Simulated AECL 4H	Dynamic Crush	Vertical
5	4	1	F112 Container	Dymanic Crush	Vertical
6	5	7	114 litre drum	Dynamic Crush	Vertical
7	6	6	208 litre drum	Dynamic Crush	Horizontal
8	7	4	Simulated AECL 4H	Dynamic Crush	Horizontal
9	8	2	F112 Container	Dynamic Crush	Horizontal
10	-	8	114 litre drum	See Note 1.	Horizontal

TABLE 1

TABLE OF DROP TESTS

Note 1. The dynamic crush test on the 114 litre drum was not carried out as the results of the same test on a 208 litre drum indicated that the drum would be crushed totally flat.



(TOTAL MASS 180kg)

FIGURE 1.

DUMMY PACKAGE

FIGURE 2

MONSERCO DROP TOWER

AND HIGH SPEED CAMERA

FIGURE 3

RIGHT, SPECIMEN NUMBER 1 AFTER DYNAMIC CRUSH TEST

LEFT, SPECIMEN NUMBER 2 BEFORE TESTING

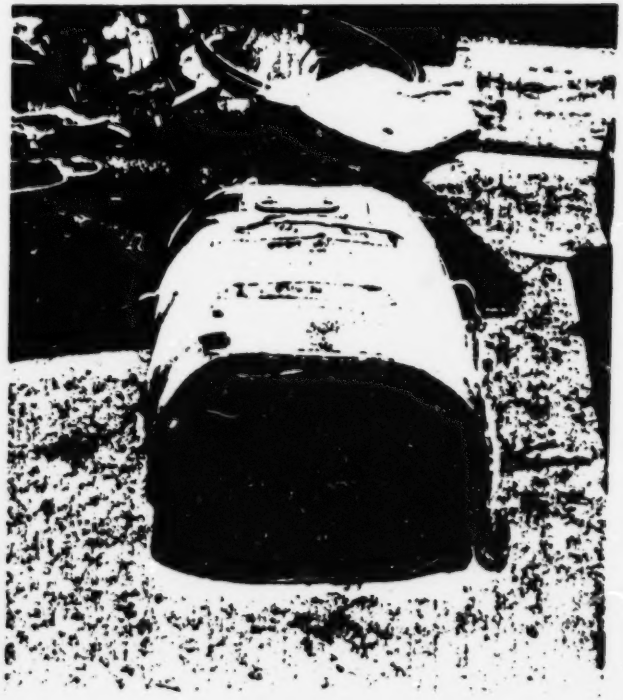


FIGURE 4

SPECIMEN NUMBER 2 AFTER

DYNAMIC CRUSH TEST

FIGURE 5

LEFT, SPECIMEN NUMBER 4 BEFORE TESTING

CENTER, SPECIMEN NUMBER 3 AFTER DYNAMIC CRUSH TEST

RIGHT, SPECIMEN NUMBER 9 AFTER 9m DROP

FIGURE 6

SPECIMEN NUMBER 3

IMMEDIATELY AFTER DYNAMIC CRUSH TEST

FIGURE 7

LEFT, SPECIMEN NUMBER 10 AFTER 9m DROP TEST

RIGHT, SPECIMEN NUMBER 4 AFTER DYNAMIC CRUSH TEST

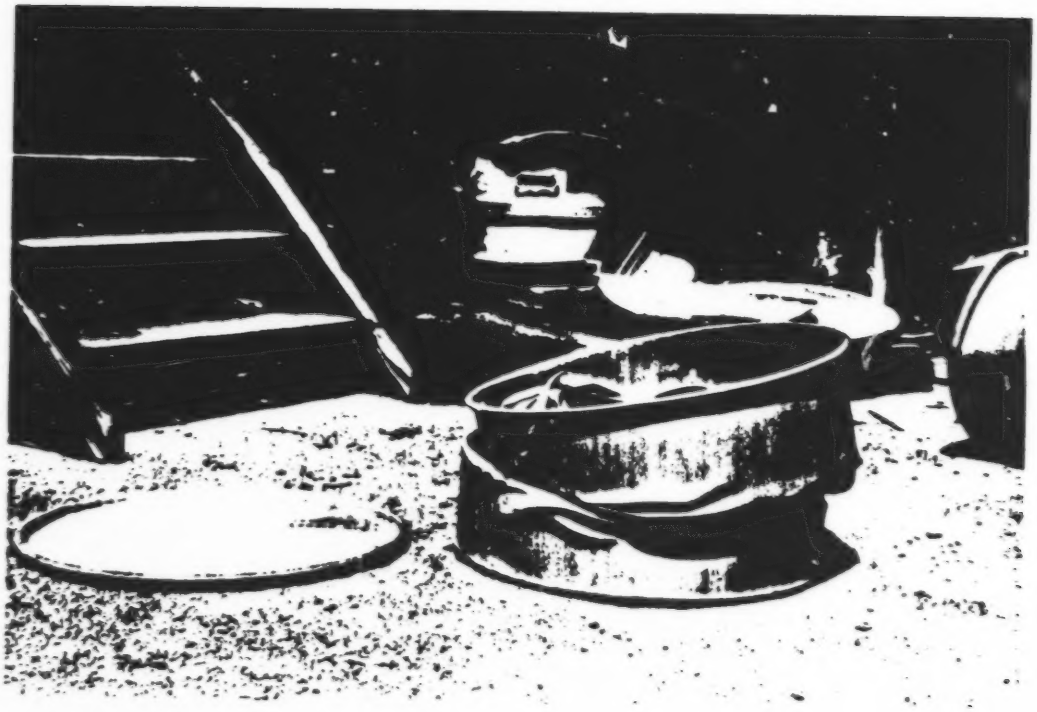


FIGURE 8

SPECIMEN NUMBER 5, 208litre EMPTY DRUM

AFTER DYNAMIC CRUSH TEST

FIGURE 9

SPECIMEN NUMBER 6, EMPTY 208 LITRE DRUM

AFTER DYNAMIC CRUSH TEST

FIGURE 10

SPECIMEN NUMBER 7, 144 LITRE EMPTY DRUM

AFTER DYNAMIC CRUSH TEST

FIGURE 11

SPECIMEN NUMBER 10

DUMMY PACKAGE AFTER 9m DROP

HORIZONTAL

APPENDIX 1.

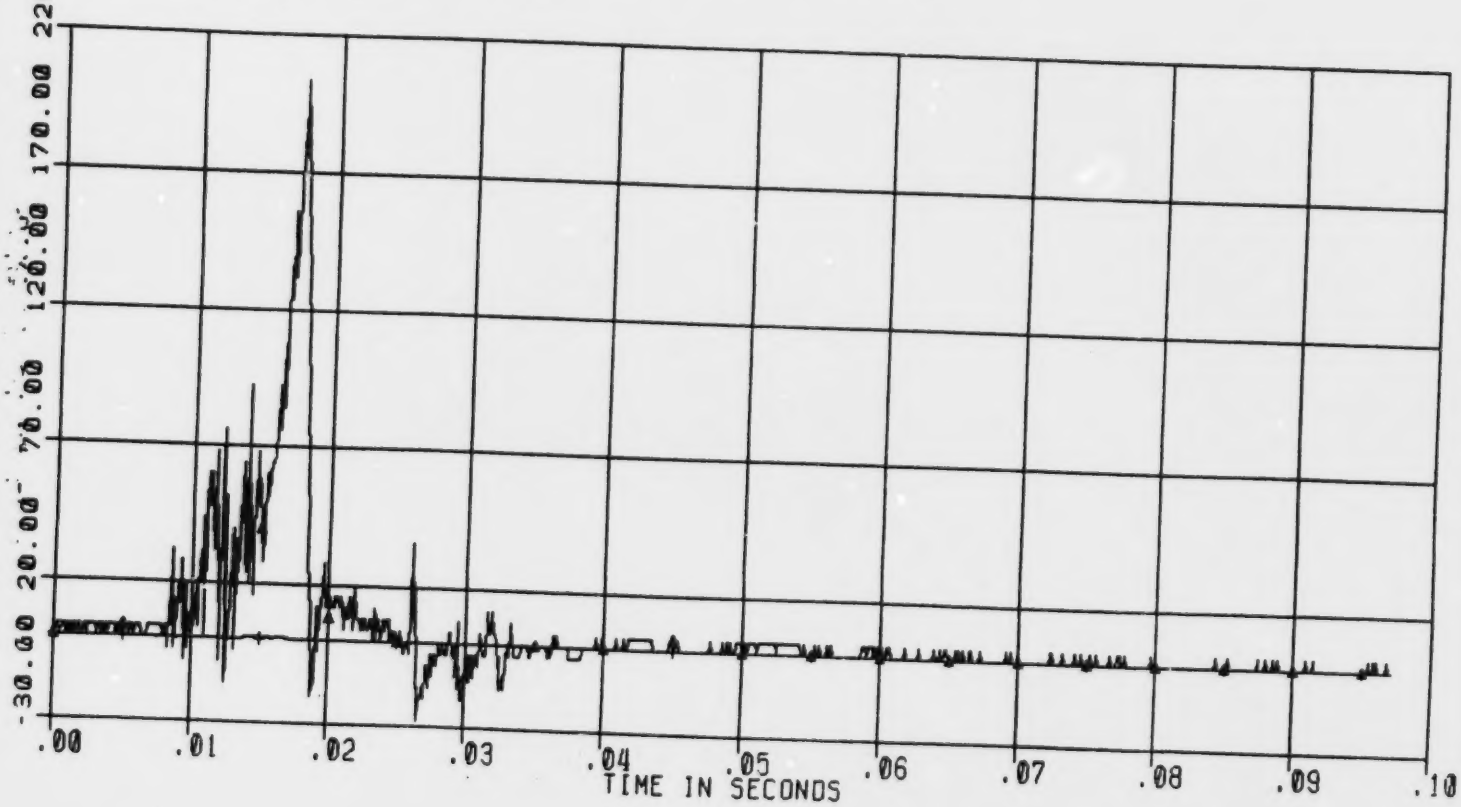
COMPUTER PLOTS

PLOTS FOR FIN TESTS

FBAR09.T
TIME 12.28
MAY 31/84

▲ ACCELERATION
+ FORCE

DROP # 3
FILM # 2
SPECIMEN # 9
SIMULATED 4H PACK.
9m DROP
VERT.

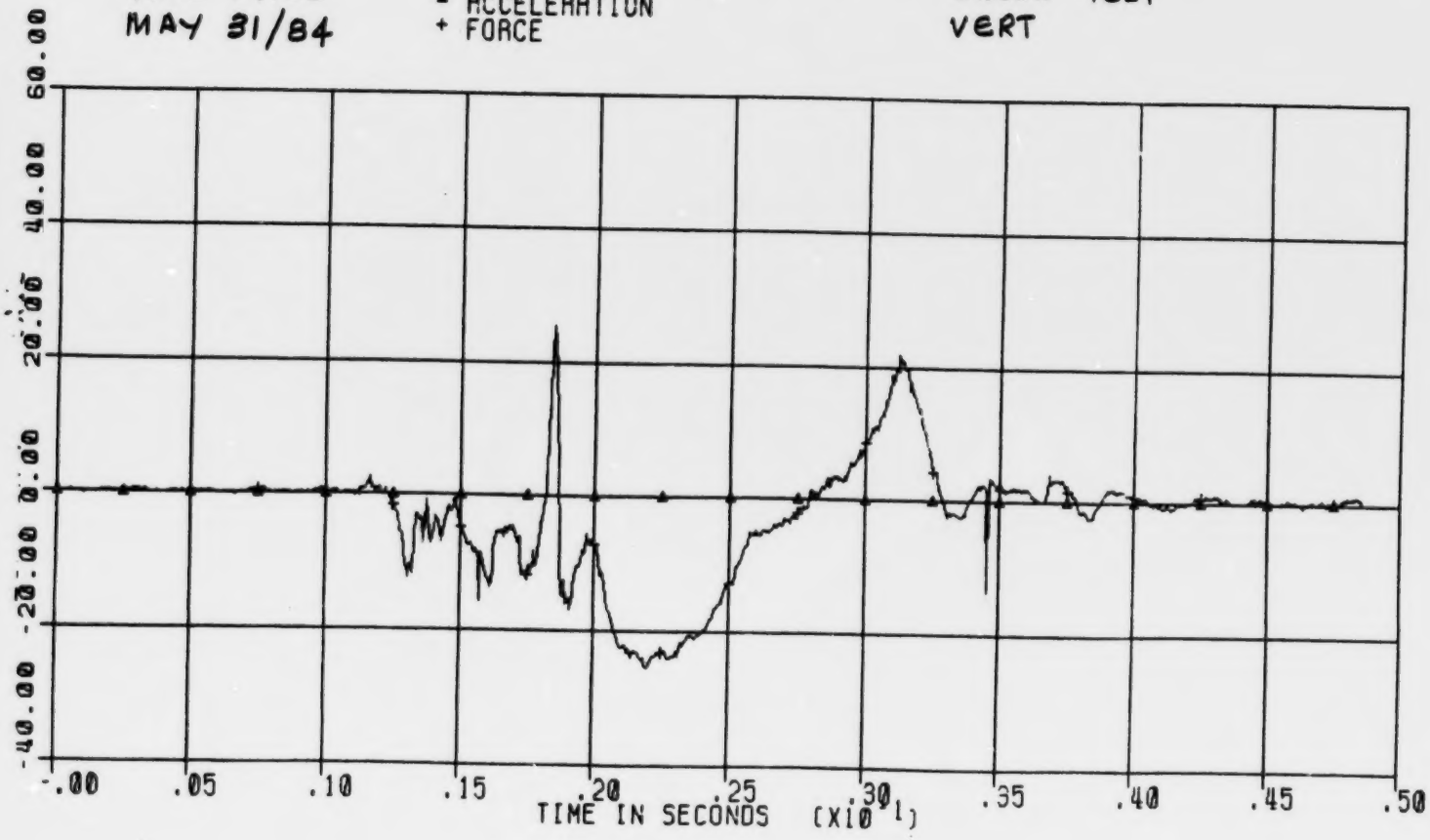


PLOTS FOR FIN TESTS

FBAR01.T
TIME 14.02
MAY 31/84

▲ ACCELERATION
+ FORCE

DROP # 5
FILM # 4
SPECIMEN # 1
F112 CONT.
CRUSH TEST
VERT

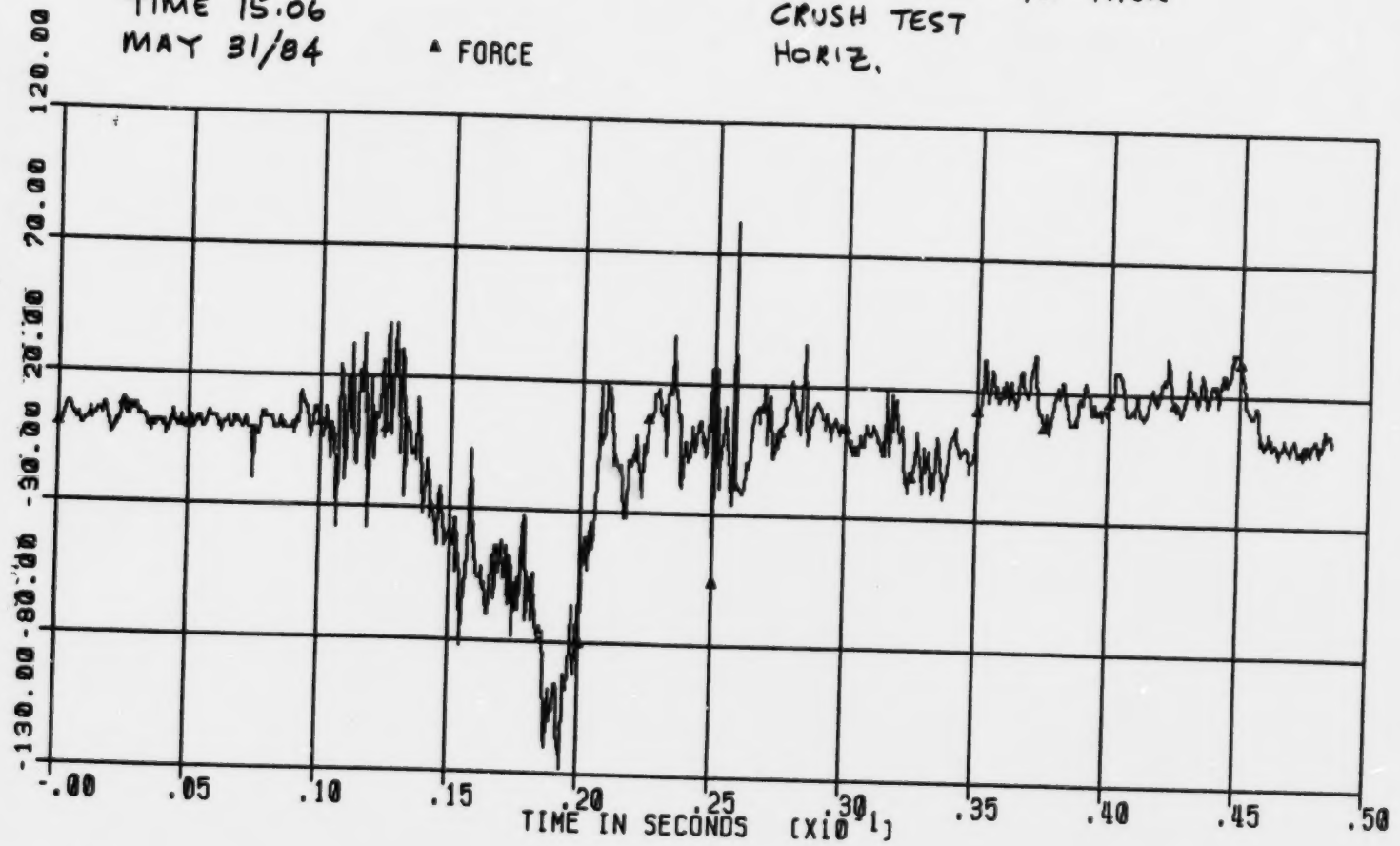


PLOTS FOR FIN TESTS

FBAR04.T
TIME 15.06
MAY 31/84

▲ FORCE

DROP # 8
FILM # 7
SPECIMEN # 4
SIMULATED 4H PACK
CRUSH TEST
HORIZ.



DROP # 9
FILM # 8
SPECIMEN # 2
F112 CONT.
CRUSH TEST
HORIZ.

PLOTS FOR FIN TESTS

FBAR02.T
TIME 15.40
MAY 31/84

▲ ACCELERATION
+ FORCE